FURTHER RESULTS FOR NON-GIMBALED ANTENNA POINTING

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SECTION 1 - INTRODUCTION

This report details the simulations run at New Mexico State University to simulate the interactions between zenith-pointing antenna on a spin-stabilized satellite and the Tracking and Data Relay Satellites (TDRS) in the Space Network (SN) operated by the National Aeronautics and Space Administration (NASA). Preliminary results for this study have been reported in [1], [2], and [3]. This report extends the preliminary study in the following ways:

1. The simulation period was extended from the previous maximum of 10 days to 30 days
2. The number of TDRS satellites in the SN constellation was enlarged to three to allow for the current TDRS positioned to close the Zone of Exclusion over the Indian Ocean
3. The simulation methodology was improved by using the commercial orbital analysis program Satellite Tool Kit.

The following sections describe the simulation environment used, the exact cases studied, the results of the simulations, and, finally, the conclusions and further work for this project.

SECTION 2 - SIMULATION ENVIRONMENT

The initial investigations [1], [2] and [3] were developed primarily using MATHCAD and Visual Basic programming environments to perform the necessary computer work. In this study, the simulation environment has been upgraded to use the commercial software product Satellite Tool Kit (STK) version 3.0 [4]. This has several advantages over the hand-coded original analysis, including perturbation models for propagating the orbital elements (STK uses the MSGP4 propagation model for all of the simulations used here) and the ability to choose the attitude control system model for the satellites. Because of the more exact mathematical model, the simulation duration was extended to 30 days over the original 1-10 day simulations reported earlier.

The STK program was run on a standard PC-compatible computer (133 MHz clock speed, 16 MB memory) running Windows 95.

SECTION 3 - CASES STUDIED

STK was configured for a constellation of three TDRS spacecraft with the orbital elements given in Table 1. The TDRS orbital elements were taken from [5]. The TDRS constellation was configured for both the nominal TDRS east (TDRS-E) and west (TDRS-W) spacecraft plus the third TDRS positioned to close the Zone of Exclusion (ZOE) over the Indian Ocean. The attitude control model for all three TDRS was set to the default of nadir alignment with ECF velocity constraint. The spinning satellite was configured in STK with the elements shown in Table 2. The attitude control model was that of a nadir-pointing, spinning satellite. An example plot showing the TDRS locations and a sample of the spinning satellite orbits over a 24-hour period is given in Figure 1.

A contact between a given TDRS and the spinning satellite occurs when the antenna model on the TDRS is visible to the antenna model on the spinning satellite as illustrated in Figure 2. At position #1 of Figure 2, the two antennas are not mutually visible while at position #2 of Figure 2, they are. The STK program tracks the time of these contacts automatically and produces a report listing them over the simulated 30-day duration. The antenna model used on the TDRS is emulating the Multiple Access antenna system. In STK, antennas are modeled as sensor objects (a generic term used for any sensor, antenna, or object on a spacecraft that STK needs to keep track of). Associated with each sensor object is its visibility. In STK, this is called its cone angle and it represents the half-angle of the cone containing the full response of the sensor. For an antenna, this total cone angle would correspond to the Half Power Beam Width (HPBW), as shown in Figure 3. The cone angle used in STK would then be one-half of the HPBW.

SECTION 4 - RESULTS

The access of the satellite was simulated over the following sets of conditions:

a. Orbital altitude covering 600 km through 1200 km

b. Orbital inclination angle covering 20° through 100°

c. Antenna cone angle of 10° through 40° corresponding to effective beamwidths of 20° through 80°.

In each of the simulations, we look at the access to each of the TDRS satellites in the SN constellation. We examine the following statistics as a function of orbital altitude, orbital inclination angle, and antenna cone angle:

Table 1. Orbital Elements for the TDRS Spacecraft Used in the STK Simulations			
element	TDRS-E	TDRS-W	TDRS-ZOE
epoch	96309.07963542	96309.52072197	96310.80322976
MM (rev/day)	1.00269234	1.00270108	1.00269000
eccentricity	0.00088320	0.00040560	0.00057810
inclination (degrees)	0.1690	0.0743	2.7767
ω_p (degrees)	119.7426	173.4374	153.3718
RAAN (degrees)	90.1551	80.9672	71.2162
MA (degrees)	181.4839	162.7795	195.2850

Table 2. Orbital Elements Used for the Spinning Satellite in the STK Simulations	
element	value
MM (rev/day)	13.16 through 14.89
Altitude (km)	600 through 1200
eccentricity	0
inclination (degrees)	20° through 100°
ω_p	0
RAAN (degrees)	0
MA (degrees)	0

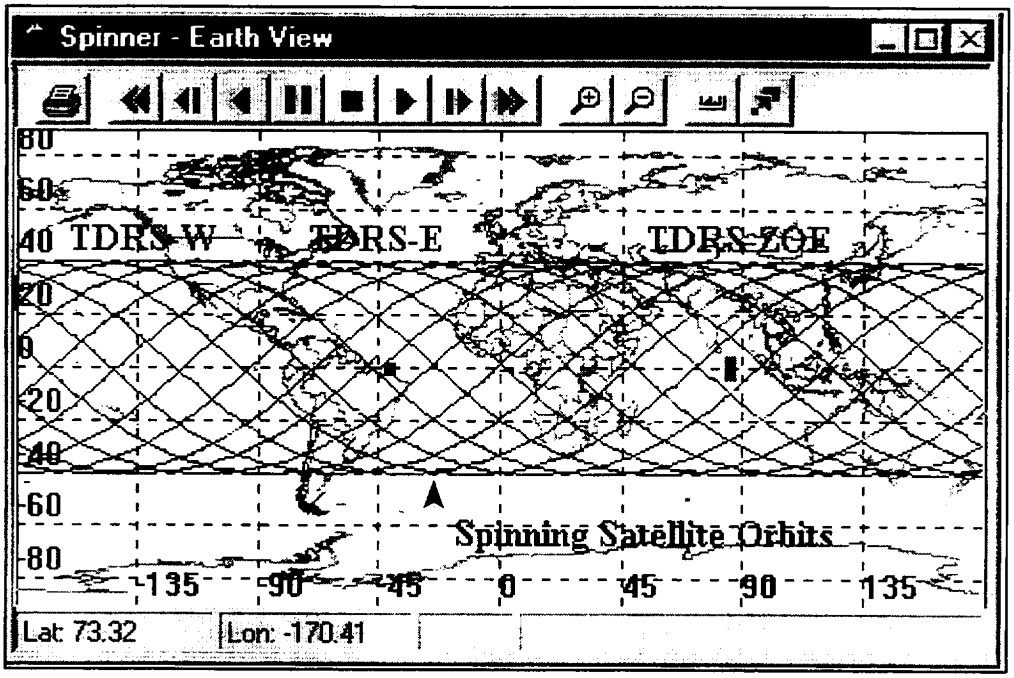


Figure 1 - Example orbital ground tracks for the three TDRS satellites and the spinning satellite over a 24-hour period using STK to perform the simulation.

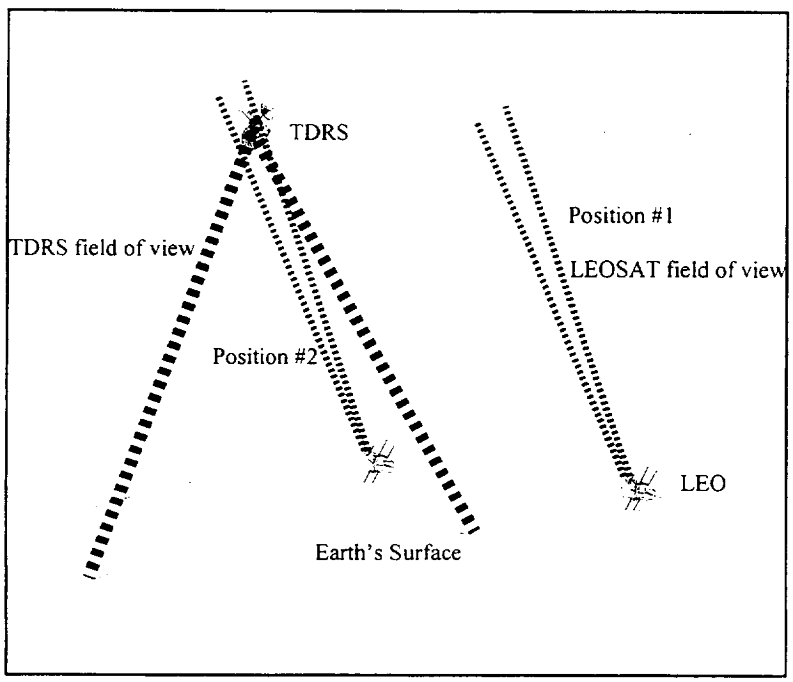


Figure 2 - TDRS/LEO Satellite Access Geometry.

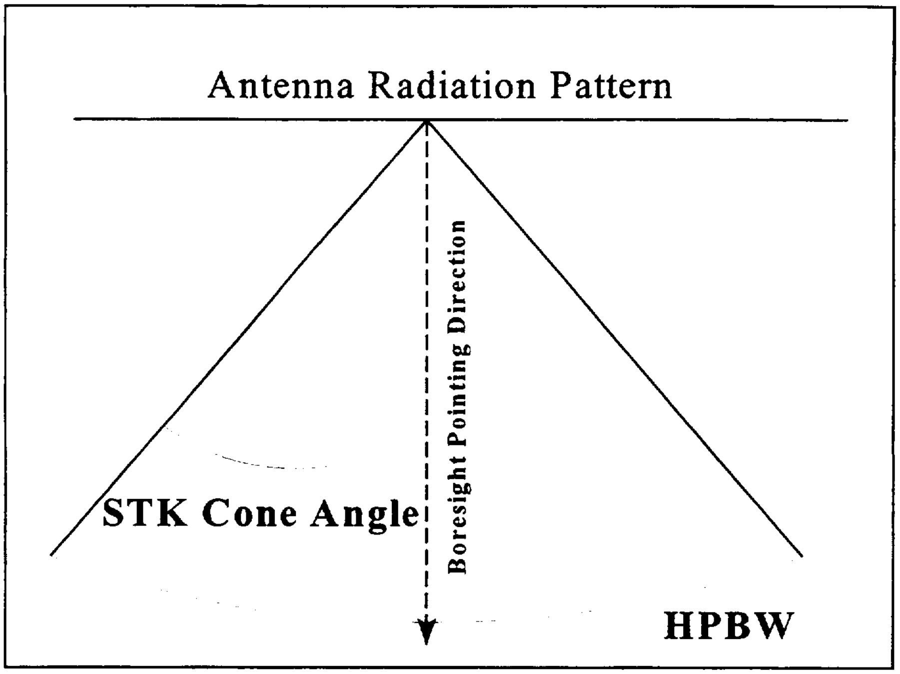


Figure 3 - Relationship between STK antenna cone Angle and antenna HPBW

a. minimum, maximum, and average contact length in minutes

b. total daily contact duration for each TDRS and the SN constellation

c. average number of contacts per day for each TDRS

d. average contact duration

Tables 3 through 6 summarize the results obtained when the simulations covered a 30-day period. Figures 4 and 5 plot the results for TDRS West illustrating the average number of contacts per day and the average contact duration. The TDRS East and ZOE satellites have very similar results so only TDRS West is shown. Figure 6 illustrates the total SN constellation average daily contact time.

Table 3. MEAN MOTION CALCULATED FROM 600 KM = 14.89329402 REVS/DAY

Half Angle			INCLINATION 20° TDRS-E	20° TDRS-W	20° TDRS-ZOE	40° TDRS-E	40° TDRS-W	40° TDRS-ZOE	60° TDRS-E	60° TDRS-W	60° TDRS-ZOE	80° TDRS-E	80° TDRS-W	80° TDRS-ZOE	100° TDRS-E	100° TDRS-W	100° TDRS-ZOE
10°	30-day	Min (sec)	20.07	38.10	31.33	93.81	25.84	35.22	86.91	50.89	42.07	38.43	34.09	69.39	49.59	55.01	53.20
		Max (sec)	286.96	287.00	287.06	283.43	283.34	351.36	278.04	278.00	278.95	271.89	271.88	272.64	265.56	265.60	265.34
		Mean (sec)	224.81	228.15	222.28	224.80	221.10	224.86	225.61	220.93	220.47	212.01	216.44	217.22	206.25	211.65	206.75
		Total Duration(sec)	26078.05	26237.61	25117.14	13712.94	13929.16	13716.53	10152.40	10162.84	10361.97	8692.19	9090.54	9123.31	9074.87	8254.45	8890.24
		Total Duration (min)	434.63	437.29	418.62	228.55	232.15	228.61	169.21	169.38	172.70	144.87	151.51	152.06	151.25	137.57	148.17
	Avg. Daily	Contact Time (sec)	869.27	874.59	837.24	457.10	464.31	457.22	338.41	338.76	345.40	289.74	303.02	304.11	302.50	275.15	296.34
		Contact Time (min)	14.49	14.58	13.95	7.62	7.74	7.62	5.64	5.65	5.76	4.83	5.05	5.07	5.04	4.59	4.94
		Number of Contacts	3.87	3.83	3.77	2.03	2.10	2.03	1.50	1.53	1.57	1.37	1.40	1.40	1.47	1.30	1.43
	Avg.	Contact Duration (sec)	224.81	228.15	222.28	224.80	221.10	224.86	225.61	220.93	220.47	212.00	216.44	217.22	206.25	211.65	206.75
		Contact Duration (min)	3.75	3.80	3.70	3.75	3.69	3.75	3.76	3.68	3.67	3.53	3.61	3.62	3.44	3.53	3.45
		Constellation Contact		43.03			22.95			17.04			14.96			14.57	
20°	30-day	Min (sec)	10.87	19.82	23.82	112.41	86.16	4.82	19.00	98.99	15.60	51.88	55.46	113.55	28.58	116.37	40.81
		Max (sec)	575.64	575.68	575.99	568.57	568.49	573.95	557.90	557.83	559.53	545.56	545.43	547.03	532.75	532.83	532.60
		Mean (sec)	434.07	434.36	433.63	445.31	447.72	448.57	439.57	439.49	439.13	426.67	433.69	437.33	422.32	419.19	413.04
		Total Duration(sec)	115463.12	115975.23	111442.61	56109.29	56412.57	56519.89	40879.78	41312.38	42156.43	36693.25	35562.81	35861.38	35897.12	36469.79	35934.04
		Total Duration (min)	1924.39	1932.92	1857.38	935.15	940.21	942.00	681.33	688.54	702.61	611.55	592.71	597.69	598.29	607.83	598.90
	Avg. Daily	Contact Time (sec)	3848.77	3865.84	3714.75	1870.31	1880.42	1884.00	1362.66	1377.08	1405.21	1223.11	1185.43	1195.38	1196.57	1215.66	1197.80
		Contact Time (min)	64.15	64.43	61.91	31.17	31.34	31.40	22.71	22.95	23.42	20.39	19.76	19.92	19.94	20.26	19.96
		Number of Contacts	8.87	8.90	8.57	4.20	4.20	4.20	3.10	3.13	3.20	2.87	2.73	2.73	2.83	2.90	2.90
	Avg.	Contact Duration (sec)	434.07	434.36	433.63	445.31	447.72	448.57	439.57	439.49	439.13	426.67	433.69	437.33	422.32	419.19	413.04
		Contact Duration (min)	7.23	7.24	7.23	7.42	7.46	7.48	7.33	7.32	7.32	7.11	7.23	7.29	7.04	6.99	6.88
		Constellation Contact		190.54			93.91			69.06			60.04			60.14	
30°	30-day	Min (sec)	538.60	542.17	390.31	80.61	35.34	94.54	93.29	97.78	142.02	102.53	137.54	42.36	126.70	150.81	75.37
		Max (sec)	867.65	867.68	868.25	857.01	856.89	858.70	841.05	840.86	843.44	822.34	822.14	824.57	803.03	803.13	802.97
		Mean (sec)	719.76	720.98	699.33	665.38	671.80	670.88	662.21	666.18	669.54	654.77	649.26	648.35	632.63	638.95	631.55
		Total Duration(sec)	300859.20	300649.79	291618.91	132116.02	131672.37	131491.62	94033.67	94597.88	96413.58	83155.39	81806.27	82339.84	82242.30	82424.27	82101.57
		Total Duration (min)	5014.32	5010.83	4860.32	2201.93	2194.54	2191.53	1567.23	1576.63	1606.89	1385.92	1363.44	1372.33	1370.71	1373.74	1368.36
	Avg. Daily	Contact time (sec)	10028.64	10021.66	9720.63	4403.87	4389.08	4383.05	3134.46	3153.26	3213.79	2771.85	2726.88	2744.66	2741.41	2747.48	2736.72
		Contact Time (min)	167.14	167.03	162.01	73.40	73.15	73.05	52.24	52.55	53.56	46.20	45.45	45.74	45.69	45.79	45.61
		Number of Contacts	13.93	13.90	13.90	6.60	6.53	6.53	4.73	4.73	4.80	4.23	4.20	4.23	4.33	4.30	4.33
	Avg.	Contact Duration (sec)	719.76	720.98	699.33	667.25	671.80	670.88	662.21	666.18	669.54	654.77	649.26	648.35	632.63	638.95	631.55
		Contact Duration (min)	12.00	12.02	11.66	11.12	11.20	11.18	11.04	11.10	11.16	10.91	10.82	10.81	10.54	10.65	10.53
		Constellation Contact		496.14			219.53			158.28			137.32			137.02	
40°	30-day	Min (sec)	872.56	967.12	896.56	63.80	62.52	43.64	59.49	144.95	16.69	54.25	148.31	114.84	84.88	176.30	103.91

			Max (sec)	1164.55	1164.56	1165.54		1150.31	1150.19	1152.56		1128.96	1128.75	1132.12		1103.91	1103.67	1106.88		1077.96	1078.10	1078.04
			Mean (sec)	1071.10	1072.27	1060.79		887.28	890.56	893.01		896.48	901.25	895.82		878.50	884.26	879.24		858.52	861.41	853.30
			Total Duration(sec)	447718.61	447137.56	442350.33		251099.91	251138.43	251851.27		172123.91	173039.83	176477.16		150222.62	149440.02	150349.39		149382.79	148162.56	149327.01
			Total Duration (min)	7461.98	7452.29	7372.51		4185.00	4185.64	4197.52		2868.73	2884.00	2941.29		2503.71	2490.67	2505.82		2489.71	2469.38	2488.78
		Avg. Daily	Contact Time (sec)	14923.95	14904.59	14745.01		8370.00	8371.28	8395.04		5737.46	5767.99	5882.57		5007.42	4981.33	5011.65		4979.43	4938.75	4977.57
			Contact Time (min)	248.73	248.41	245.75		139.50	139.52	139.92		95.62	96.13	98.04		83.46	83.02	83.53		82.99	82.31	82.96
			Number of Contacts	13.93	13.90	13.90		9.43	9.40	9.40		6.40	6.40	6.57		5.70	5.63	5.70		5.80	5.73	5.83
		Avg.	Contact Duration (sec)	1071.10	1072.27	1060.79		887.28	890.56	893.09		896.48	901.25	895.82		878.49	884.26	879.24		858.52	861.41	853.30
			Contact Duration (min)	17.85	17.87	17.68		14.79	14.84	14.88		14.94	15.02	14.93		14.64	14.74	14.65		14.31	14.36	14.22
			Constellation Contact		742.83				418.89				289.85				249.96				248.17	

Table 4. MEAN MOTION CALCULATED FROM 800 KM = 14.27520838 REVS/DAY

Half Angle			INCLINATION 20°			40°			60°			80°			100°		
			TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE
10°	30-day	Min (sec)	24.05	28.20	13.14	22.17	11.69	43.23	172.87	69.84	50.55	62.45	106.87	33.82	86.08	26.68	78.04
		Max (sec)	298.57	298.57	298.90	294.66	294.63	295.18	287.04	288.88	289.76	281.91	282.17	329.96	275.38	274.56	275.15
		Mean (sec)	231.00	231.46	223.32	227.63	229.51	227.77	242.58	226.29	222.07	216.81	227.94	220.93	223.74	204.09	223.74
		Total Duration(sec)	26102.59	26386.28	25234.95	13657.76	13311.80	13665.91	9945.73	10182.82	10215.26	8889.12	8889.49	8837.22	8726.03	8979.73	8949.39
		Total Duration (min)	435.04	439.77	420.58	227.63	221.86	227.77	165.76	169.71	170.25	148.15	148.16	147.29	145.43	149.66	149.16
	Avg. Daily	Contact Time (sec)	870.09	879.54	841.17	455.26	443.73	455.53	331.52	339.43	340.51	296.30	296.32	294.57	290.87	299.32	298.31
		Contact Time (min)	14.50	14.66	14.02	7.59	7.40	7.59	5.53	5.66	5.68	4.94	4.94	4.91	4.85	4.99	4.97
		Number of Contacts	3.77	3.80	3.77	2.00	1.93	2.00	1.37	1.50	1.53	1.37	1.30	1.33	1.30	1.47	1.33
	Avg.	Contact Duration (sec)	231.00	231.46	223.32	227.63	229.51	227.77	242.58	226.28	222.07	216.81	227.94	220.93	223.74	204.08	223.73
		Contact Duration (min)	3.85	3.86	3.72	3.79	3.83	3.80	4.04	3.77	3.70	3.61	3.80	3.68	3.73	3.40	3.73
		Constellation Contact		43.21			22.56			16.86			14.79			14.81	
20°	30-day	Min (sec)	22.75	30.60	36.12	135.38	112.66	48.49	9.44	88.86	86.99	107.98	30.89	64.62	50.92	108.72	74.72
		Max (sec)	598.96	598.98	599.70	591.16	591.12	592.46	578.76	579.57	581.32	565.97	566.09	567.62	552.41	552.04	552.06
		Mean (sec)	455.49	454.12	447.11	468.60	466.94	460.52	436.98	457.07	460.42	443.24	442.00	445.07	435.60	437.32	434.55
		Total Duration(sec)	114326.77	114891.71	113566.14	55762.90	55098.48	56183.74	40638.91	40679.11	40977.54	35902.24	35360.23	35605.71	35718.92	35422.55	35633.04
		Total Duration (min)	1905.45	1914.86	1892.77	929.38	918.31	936.40	677.32	677.99	682.96	598.37	589.34	593.43	595.32	590.38	593.88
	Avg. Daily	Contact Time (sec)	3810.89	3829.72	3785.54	1858.76	1836.62	1872.79	1354.63	1355.97	1365.92	1196.74	1178.67	1186.86	1190.63	1180.75	1187.77
		Contact Time (min)	63.51	63.83	63.09	30.98	30.61	31.21	22.58	22.60	22.77	19.95	19.64	19.78	19.84	19.68	19.80
		Number of Contacts	8.37	8.43	8.47	3.97	3.93	4.07	3.10	2.97	2.97	2.70	2.67	2.67	2.73	2.70	2.73
	Avg.	Contact Duration (sec)	455.49	454.12	447.11	468.60	466.94	460.52	436.98	457.07	460.42	443.24	442.00	445.07	435.60	437.32	434.55
		Contact Duration (min)	7.59	7.57	7.45	7.81	7.78	7.68	7.28	7.62	7.67	7.39	7.37	7.42	7.26	7.29	7.24
		Constellation Contact		190.46			92.83			67.99			59.42			59.27	
30°	30-day	Min (sec)	556.80	559.74	396.51	94.22	88.28	13.97	251.20	80.48	65.86	102.44	24.87	150.40	83.42	19.23	78.10
		Max (sec)	902.93	902.98	904.05	891.23	891.21	893.26	873.37	873.77	876.39	853.47	853.46	855.82	832.85	832.56	832.58
		Mean (sec)	748.52	748.73	733.42	701.57	698.42	693.79	692.41	696.93	688.37	675.08	668.62	676.86	661.14	663.35	652.43
		Total Duration(sec)	298659.48	298744.08	291900.30	130491.69	129208.32	131820.52	93475.37	93388.60	94994.54	82359.99	80903.53	81900.17	81320.22	80928.95	81553.88
		Total Duration (min)	4977.66	4979.07	4865.01	2174.86	2153.47	2197.01	1557.92	1556.48	1583.24	1372.67	1348.39	1365.00	1355.34	1348.82	1359.23
	Avg. Daily	Contact Time (sec)	9955.32	9958.14	9730.01	4349.72	4306.94	4394.02	3115.85	3112.95	3166.48	2745.33	2696.78	2730.01	2710.67	2697.63	2718.46
		Contact Time (min)	165.92	165.97	162.17	72.50	71.78	73.23	51.93	51.88	52.77	45.76	44.95	45.50	45.18	44.96	45.31
		Number of Contacts	13.30	13.30	13.27	6.20	6.17	6.33	4.50	4.47	4.60	4.07	4.03	4.03	4.10	4.07	4.17
	Avg.	Contact Duration (sec)	748.52	748.73	733.42	701.57	698.42	693.79	692.41	696.93	688.37	675.08	668.62	676.86	661.14	663.35	652.43
		Contact Duration (min)	12.48	12.48	12.22	11.69	11.64	11.56	11.54	11.62	11.47	11.25	11.14	11.28	11.02	11.06	10.87
		Constellation Contact		494.10			217.51			156.63			136.16			135.52	
40°	30-day	Min (sec)	1003.14	1004.66	929.71	48.97	68.94	78.40	64.04	143.91	141.51	197.29	117.35	70.28	112.96	298.47	79.42

	Max (sec)	1212.16	1212.23	1213.66	1196.55	1196.50	1199.25	1172.96	1173.16	1176.65	1145.98	1145.88	1149.11	1118.16	1118.00	1118.07
	Mean (sec)	1115.25	1115.39	1107.63	923.63	922.15	923.75	925.23	938.09	932.14	914.65	915.68	915.45	888.71	899.89	880.62
	Total Duration(sec)	444983.97	445041.28	440836.75	248456.26	247921.80	253106.19	170242.40	171671.10	174309.66	149087.75	147423.95	148302.57	147526.43	147582.44	147944.00
	Total Duration (min)	7416.40	7417.35	7347.28	4140.94	4132.03	4218.44	2837.37	2861.19	2905.16	2484.80	2457.07	2471.71	2458.77	2459.71	2465.73
Avg. Daily	Contact Time (sec)	14832.80	14834.71	14694.56	8281.88	8264.06	8436.87	5674.75	5722.37	5810.32	4969.59	4914.13	4943.42	4917.55	4919.41	4931.47
	Contact Time (min)	247.21	247.25	244.91	138.03	137.73	140.61	94.58	95.37	96.84	82.83	81.90	82.39	81.96	81.99	82.19
	Number of Contacts	13.30	13.30	13.27	8.97	8.97	9.13	6.13	6.10	6.23	5.43	5.37	5.40	5.53	5.47	5.60
Avg.	Contact Duration (sec)	1115.25	1115.39	1107.63	923.63	921.64	923.75	925.23	938.09	932.14	914.65	915.68	915.45	888.71	899.89	880.62
	Contact Duration (min)	18.59	18.59	18.46	15.39	15.36	15.40	15.42	15.63	15.54	15.24	15.26	15.26	14.81	15.00	14.68
	Constellation Contact		739.43			416.43			286.69			247.12			246.14	

Table 5. MEAN MOTION CALCULATED FROM 1000 KM = 13.69872239 REVS/DAY

				INCLINATION														
				20°			40°			60°			80°			100°		
Half Angle	10°			TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE
		30-day	Min (sec)	37.05	20.28	24.32	57.41	50.78	12.44	66.96	99.08	10.66	28.17	36.53	44.74	62.53	30.81	26.61
			Max (sec)	310.35	310.32	310.57	305.96	305.62	306.63	299.75	299.76	300.71	292.51	292.47	449.00	344.61	284.78	284.63
			Mean (sec)	244.86	241.44	235.71	238.61	236.49	240.27	240.81	244.18	229.83	219.55	229.15	237.05	223.03	229.00	220.33
			Total Duration(sec)	25465.82	25592.88	25928.55	13839.30	13952.78	12974.73	9632.50	10011.38	9882.51	8782.09	8478.70	9007.82	8698.10	8472.84	8813.27
			Total Duration (min)	424.43	426.55	432.14	230.66	232.55	216.25	160.54	166.86	164.71	146.37	141.31	150.13	144.97	141.21	146.89
		Avg. Daily	Contact Time (sec)	848.86	853.10	864.29	461.31	465.09	432.49	321.08	333.71	329.42	292.74	282.62	300.26	289.94	282.43	293.78
			Contact Time (min)	14.15	14.22	14.40	7.69	7.75	7.21	5.35	5.56	5.49	4.88	4.71	5.00	4.83	4.71	4.90
			Number of Contacts	3.47	3.53	3.67	1.93	1.97	1.80	1.33	1.37	1.43	1.33	1.23	1.27	1.30	1.23	1.33
		Avg.	Contact Duration (sec)	244.86	241.44	235.71	238.61	236.49	240.27	240.81	244.18	229.83	219.55	229.15	237.05	223.03	229.00	220.33
			Contact Duration (min)	4.08	4.02	3.93	3.98	3.94	4.00	4.01	4.07	3.83	3.66	3.82	3.95	3.72	3.82	3.67
			Constellation Contact		42.78			22.65			16.39			14.58			14.41	
	20°	30-day	Min (sec)	46.61	31.51	27.52	66.20	70.31	41.83	60.58	25.72	96.44	12.24	46.06	22.83	63.63	91.92	88.05
			Max (sec)	622.64	622.64	623.33	614.01	613.75	615.40	601.47	601.40	603.37	586.88	586.77	588.18	571.98	571.90	571.72
			Mean (sec)	470.32	467.80	462.94	479.19	471.98	490.86	470.83	477.86	476.29	452.02	455.31	462.12	452.69	448.36	450.57
			Total Duration(sec)	113346.00	113207.12	115273.28	54627.68	55222.00	55467.71	40020.90	40140.14	40960.58	35709.24	35058.80	35120.99	34857.14	34971.99	35595.29
			Total Duration (min)	1889.10	1886.79	1921.22	910.46	920.37	924.46	667.02	669.00	682.68	595.15	584.31	585.35	580.95	582.87	593.25
		Avg. Daily	Contact Time (sec)	3778.20	3773.57	3842.44	1820.92	1840.73	1848.92	1334.03	1338.00	1365.35	1190.31	1168.63	1170.70	1161.90	1165.73	1186.51
			Contact Time (min)	62.97	62.89	64.04	30.35	30.68	30.82	22.23	22.30	22.76	19.84	19.48	19.51	19.37	19.43	19.78
			Number of Contacts	8.03	8.07	8.30	3.80	3.90	3.77	2.83	2.80	2.87	2.63	2.57	2.53	2.57	2.60	2.63
		Avg.	Contact Duration (sec)	470.32	467.80	462.94	479.19	471.98	490.86	470.83	477.86	476.29	452.02	455.31	462.12	452.69	448.36	450.57
			Contact Duration (min)	7.84	7.80	7.72	7.99	7.87	8.18	7.85	7.96	7.94	7.53	7.59	7.70	7.54	7.47	7.51
			Constellation Contact		189.90			91.87			67.29			58.80			58.57	
	30°	30-day	Min (sec)	573.77	393.31	157.90	44.26	96.39	16.01	51.81	89.01	89.46	38.08	91.06	112.06	145.40	52.07	74.18
			Max (sec)	938.78	938.78	939.84	925.86	925.58	927.98	906.99	906.85	909.75	884.98	884.81	887.31	862.58	862.43	862.64
			Mean (sec)	776.84	775.15	769.54	716.57	718.24	704.57	718.00	719.49	720.61	692.80	693.14	698.35	688.26	670.95	682.70
			Total Duration(sec)	295976.87	296108.38	293965.05	128982.76	129284.10	131754.68	91904.70	92814.13	94399.38	81751.00	80403.81	80309.98	80526.19	79843.56	80558.41
			Total Duration (min)	4932.95	4935.14	4899.42	2149.71	2154.73	2195.91	1531.74	1546.90	1573.32	1362.52	1340.06	1338.50	1342.10	1330.73	1342.64
		Avg. daily	Contact Time (sec)	9865.90	9870.28	9798.83	4299.43	4309.47	4391.82	3063.49	3093.80	3146.65	2725.03	2680.13	2677.00	2684.21	2661.45	2685.28
			Contact Time (min)	164.43	164.50	163.31	71.66	71.82	73.20	51.06	51.56	52.44	45.42	44.67	44.62	44.74	44.36	44.75
			Number of Contacts	12.70	12.73	12.73	6.00	6.00	6.23	4.27	4.30	4.37	3.93	3.87	3.83	3.90	3.97	3.93
		Avg.	Contact Duration (sec)	776.84	775.15	769.54	716.57	718.24	704.57	718.01	719.49	720.61	692.81	693.14	698.35	688.26	670.95	682.70
			Contact Duration (min)	12.95	12.92	12.83	11.94	11.97	11.74	11.97	11.99	12.01	11.55	11.55	11.64	11.47	11.18	11.38
			Constellation Contact		492.16			216.64			155.15			134.66			133.85	
	40°	30-day	Min (sec)	1041.64	559.74	429.30	78.34	58.00	67.33	83.68	140.92	57.94	173.55	221.24	270.75	121.13	254.53	137.68

			Max (sec)	1260.52	1260.54	1261.99		1243.29	1242.96	1246.22		1218.03	1217.79	1221.75		1188.44	1188.21	1191.73		1158.40	1158.27	1158.67
			Mean (sec)	1159.01	1157.04	1154.75		965.88	972.74	952.09		967.82	972.29	966.33		950.57	953.22	957.38		916.39	932.47	926.35
			Total Duration(sec)	441583.57	441989.34	441112.91		244368.98	244158.30	254208.94		168401.61	170151.54	172972.55		147338.08	145842.54	146479.05		145705.49	145464.84	146363.31
			Total Duration (min)	7359.73	7366.49	7351.88		4072.82	4069.31	4236.82		2806.69	2835.86	2882.88		2455.63	2430.71	2441.32		2428.42	2424.41	2439.39
		Avg. Daily	Contact Time (sec)	14719.45	14732.98	14703.76		8145.63	8138.61	8473.63		5613.39	5671.72	5765.75		4911.27	4861.42	4882.64		4856.85	4848.83	4878.78
			Contact Time (min)	245.32	245.55	245.06		135.76	135.64	141.23		93.56	94.53	96.10		81.85	81.02	81.38		80.95	80.81	81.31
			Number of Contacts	12.70	12.73	12.73		8.43	8.37	8.90		5.80	5.83	5.97		5.17	5.10	5.10		5.30	5.20	5.27
		Avg.	Contact Duration (sec)	1159.01	1157.04	1154.75		965.89	972.74	952.09		967.83	972.29	966.33		950.57	953.22	957.38		916.39	932.47	926.35
			Contact Duration (min)	19.32	19.28	19.25		16.10	16.21	15.87		16.13	16.20	16.11		15.84	15.89	15.96		15.27	15.54	15.44
			Constellation Contact		735.81				412.63				284.18				244.31				243.13	

Table 6. MEAN MOTION CALCULATED FROM 1200 KM = 13.1600191 REVS/DAY

				INCLINATION														
				20°			40°			60°			80°			100°		
Half Angle	10°			TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE	TDRS-E	TDRS-W	TDRS-ZOE
		30-day	Min (sec)	17.88	39.54	26.03	173.33	273.75	53.10	34.58	69.63	36.81	66.44	46.65	53.54	110.58	51.94	21.32
			Max (sec)	322.18	408.67	322.58	436.79	317.52	307.89	310.64	310.66	382.19	302.62	302.76	303.59	294.20	294.84	294.63
			Mean (sec)	251.92	257.09	248.75	270.48	305.85	236.81	242.38	258.92	219.11	227.73	233.71	240.98	236.65	226.58	227.09
			Total Duration(sec)	25443.67	24937.86	26118.39	16228.90	18656.54	12551.06	11149.44	11651.23	7887.94	7287.24	8179.93	9880.24	8046.24	8156.89	9310.85
			Total Duration (min)	424.06	415.63	435.31	270.48	310.94	209.18	185.82	194.19	131.47	121.45	136.33	164.67	134.10	135.95	155.18
		Avg. Daily	Contact Time (sec)	848.12	831.26	870.61	540.96	621.88	418.37	371.65	388.37	262.93	242.91	272.66	329.34	268.21	271.90	310.36
			Contact Time (min)	14.14	13.85	14.51	9.02	10.36	6.97	6.19	6.47	4.38	4.05	4.54	5.49	4.47	4.53	5.17
			Number of Contacts	3.37	3.23	3.50	2.00	2.03	1.77	1.53	1.50	1.20	1.07	1.17	1.37	1.13	1.20	1.37
		Avg.	Contact Duration (sec)	251.92	257.09	248.75	270.48	305.85	236.81	242.38	258.92	219.11	227.73	233.71	240.98	236.65	226.58	227.09
			Contact Duration (min)	4.20	4.28	4.15	4.51	5.10	3.95	4.04	4.32	3.65	3.80	3.90	4.02	3.94	3.78	3.78
			Constellation Contact		42.50			26.35			17.04			14.12			14.17	
	20°	30-day	Min (sec)	46.44	30.28	53.12	82.34	46.90	83.10	73.00	56.11	45.91	116.38	111.71	124.85	174.90	9.70	94.72
			Max (sec)	646.44	646.38	647.26	635.92	637.08	631.89	623.47	623.36	620.39	607.57	607.55	609.31	591.27	591.67	591.68
			Mean (sec)	489.16	489.03	487.84	478.23	495.77	498.28	514.89	513.65	468.91	466.58	474.66	499.25	464.84	457.68	475.11
			Total Duration(sec)	112017.22	111498.22	119034.19	52605.12	43627.84	58298.46	38616.55	39551.15	41264.04	34993.47	34650.14	34947.35	34862.96	34783.82	35158.20
			Total Duration (min)	1866.95	1858.30	1983.90	876.75	727.13	971.64	643.61	659.19	687.73	583.22	577.50	582.46	581.05	579.73	585.97
		Avg. Daily	Contact Time (sec)	3733.91	3716.61	3967.81	1753.50	1454.26	1943.28	1287.22	1318.37	1375.47	1166.45	1155.00	1164.91	1162.10	1159.46	1171.94
			Contact Time (min)	62.23	61.94	66.13	29.23	24.24	32.39	21.45	21.97	22.92	19.44	19.25	19.42	19.37	19.32	19.53
			Number of Contacts	7.63	7.60	8.13	3.67	2.93	3.90	2.50	2.57	2.93	2.50	2.43	2.33	2.50	2.53	2.47
		Avg.	Contact Duration (sec)	489.16	489.03	487.85	478.23	495.77	498.28	514.89	513.65	468.91	466.58	474.66	499.25	464.84	457.68	475.11
			Contact Duration (min)	8.15	8.15	8.13	7.97	8.26	8.30	8.58	8.56	7.82	7.78	7.91	8.32	7.75	7.63	7.92
			Constellation Contact		190.25			85.85			66.35			58.05			58.23	
	30°	30-day	Min (sec)	598.11	529.94	442.17	139.66	449.36	66.80	101.31	77.37	274.00	108.74	123.11	119.64	250.01	153.05	120.30
			Max (sec)	974.81	974.72	976.04	960.00	960.73	956.83	940.26	940.14	939.76	916.36	916.25	919.03	892.04	892.30	892.57
			Mean (sec)	805.13	803.02	810.14	725.09	752.85	728.13	737.54	726.60	789.51	731.28	726.02	724.91	715.45	710.48	699.18
			Total Duration(sec)	293872.74	293906.98	295700.25	131966.13	137771.54	131063.85	89980.53	90098.81	95530.84	82635.15	79861.92	77565.69	80130.76	80284.55	79006.91
			Total Duration (min)	4897.88	4898.45	4928.34	2199.44	2296.19	2184.40	1499.68	1501.65	1592.18	1377.25	1331.03	1292.76	1335.51	1338.08	1316.78
		Avg. Daily	Contact Time (sec)	9795.76	9796.90	9856.67	4398.87	4592.38	4368.79	2999.35	3003.29	3184.36	2754.50	2662.06	2585.52	2671.03	2676.15	2633.56
			Contact Time (min)	163.26	163.28	164.28	73.31	76.54	72.81	49.99	50.05	53.07	45.91	44.37	43.09	44.52	44.60	43.89
			Number of Contacts	12.17	12.20	12.17	6.07	6.10	6.00	4.07	4.13	4.03	3.77	3.67	3.57	3.73	3.77	3.77
		Avg.	Contact Duration (sec)	805.13	803.02	810.14	725.09	752.85	728.13	737.55	726.60	789.51	731.28	726.02	724.91	715.45	710.48	699.18
			Contact Duration (min)	13.42	13.38	13.50	12.08	12.55	12.14	12.29	12.11	13.16	12.19	12.10	12.08	11.92	11.84	11.65
			Constellation Contact		490.91			222.71			153.07			133.49			133.05	
	40°	30-day	Min (sec)	1082.35	706.88	1010.35	262.18	18.18	242.61	204.30	145.28	154.86	83.14	124.12	83.91	115.57	98.22	195.57
			Max (sec)	1309.19	1309.10	1310.86	1289.99	1290.38	1287.23	1263.00	1262.81	1264.28	1230.96	1230.77	1234.54	1198.46	1198.58	1199.04

	Mean (sec)	1203.05	1200.34	1206.68	994.37	963.60	1034.60	999.25	1007.96	999.72	1006.38	985.13	963.51	951.98	957.37	942.40
	Total Duration(sec)	439113.20	439325.09	440437.38	241632.43	232227.62	251408.14	169872.80	171352.79	166952.67	143912.28	143828.54	146454.20	143748.66	143605.75	146071.31
	Total Duration (min)	7318.55	7322.08	7340.62	4027.21	3870.46	4190.14	2831.21	2855.88	2782.54	2398.54	2397.14	2440.90	2395.81	2393.43	2434.52
Avg. Daily	Contact Time (sec)	14637.11	14644.17	14681.25	8054.41	7740.92	8380.27	5662.43	5711.76	5565.09	4797.08	4794.28	4881.81	4791.62	4786.86	4869.04
	Contact Time (min)	243.95	244.07	244.69	134.24	129.02	139.67	94.37	95.20	92.75	79.95	79.90	81.36	79.86	79.78	81.15
	Number of Contacts	12.17	12.20	12.17	8.10	8.03	8.10	5.67	5.67	5.57	4.77	4.87	5.07	5.03	5.00	5.17
Avg.	Contact Duration (sec)	1203.05	1200.34	1206.68	994.37	963.60	1034.60	999.25	1007.96	999.72	1006.38	985.13	963.51	951.98	957.37	942.40
	Contact Duration (min)	20.05	20.01	20.11	16.57	16.06	17.24	16.65	16.80	16.66	16.77	16.42	16.06	15.87	15.96	15.71
	Constellation Contact		732.84			402.87			282.49			241.38			240.79	

Figure 4. Average Number of Contacts per Day as a Function of Orbital Altitude, Orbital Inclination Angle, and Antenna Cone Angle for TDRS West

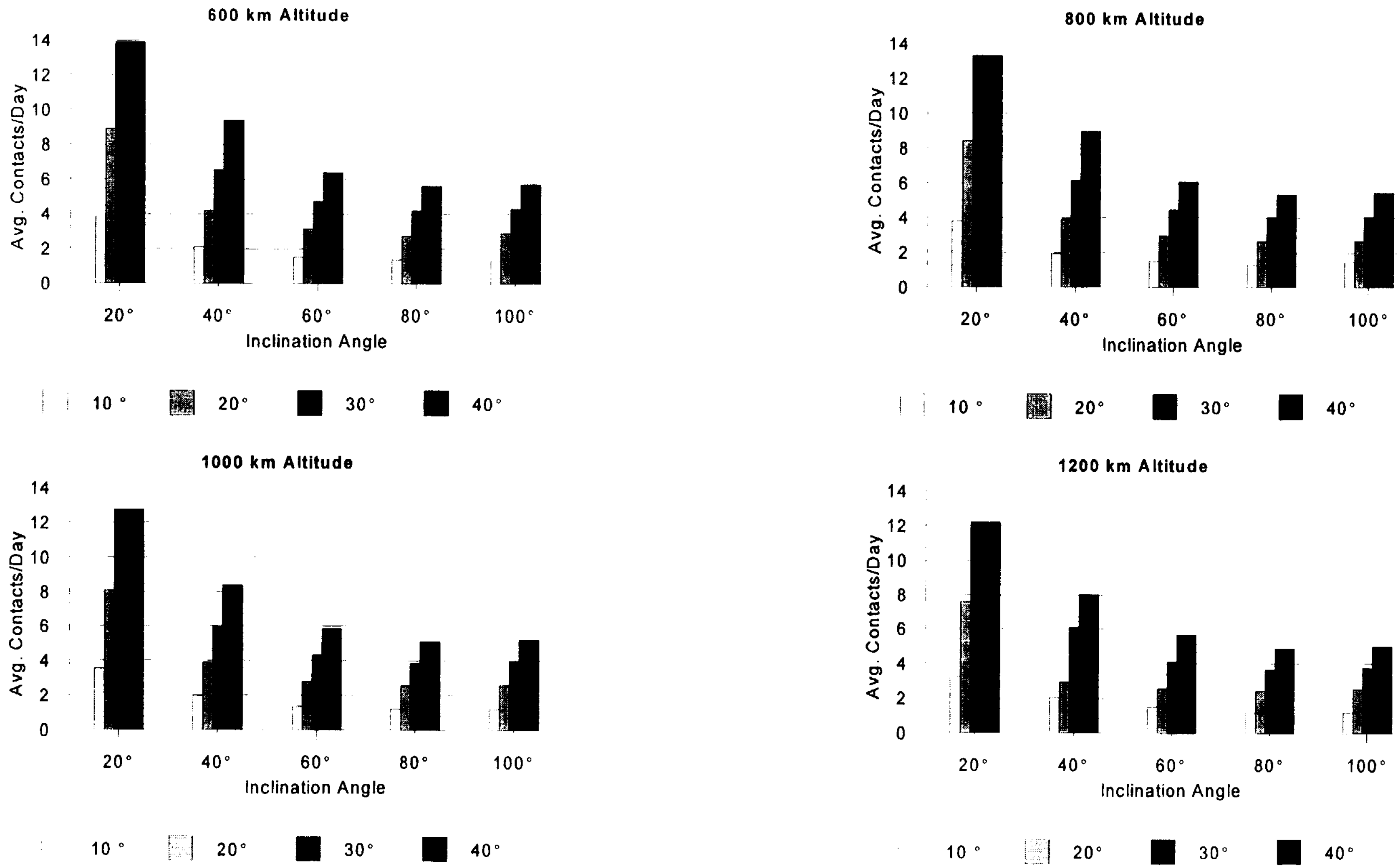


Figure 5. Average Contact Duration as a Function of Orbital Altitude, Orbital Inclination Angle, and Antenna Cone Angle for TDRS West

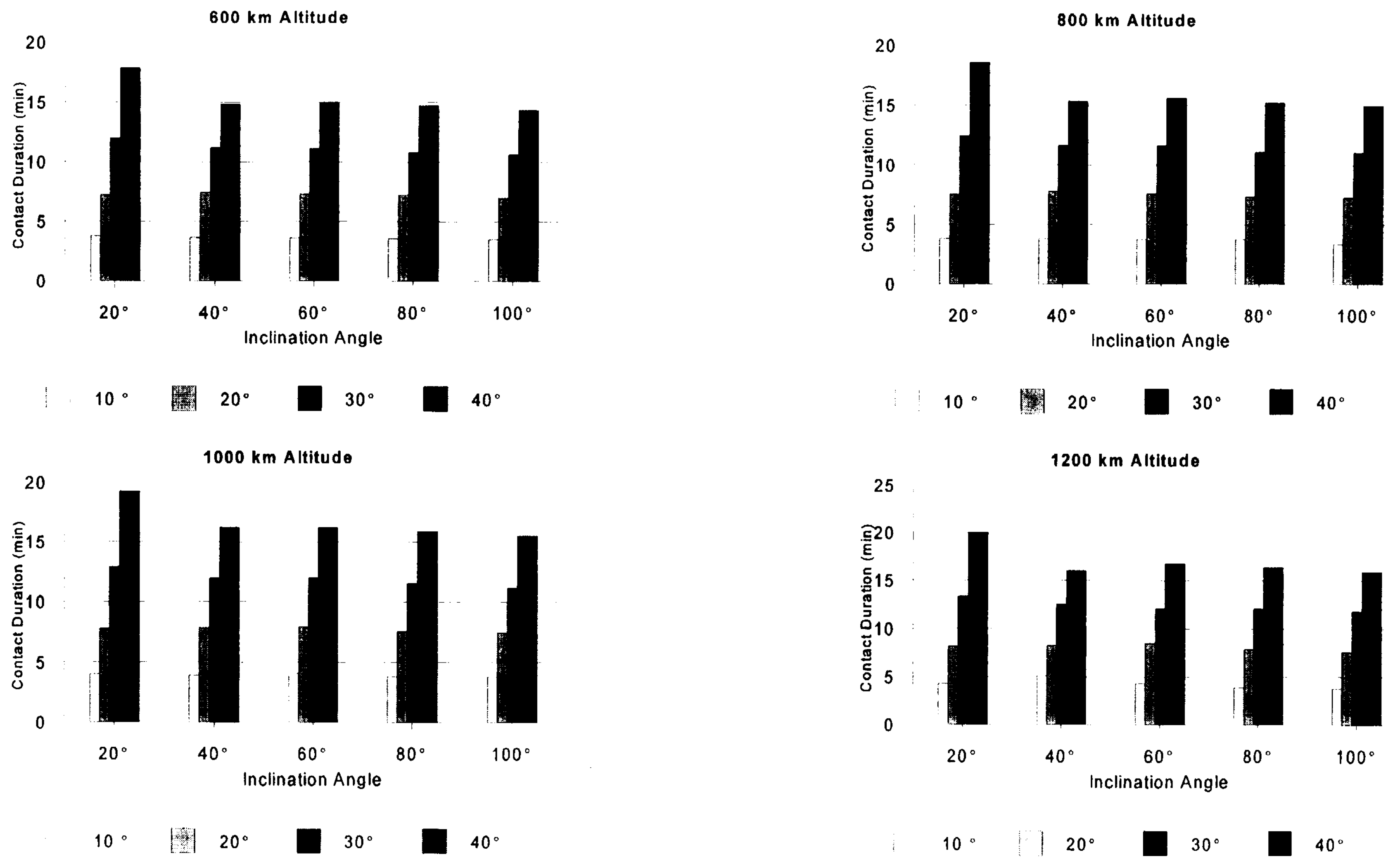
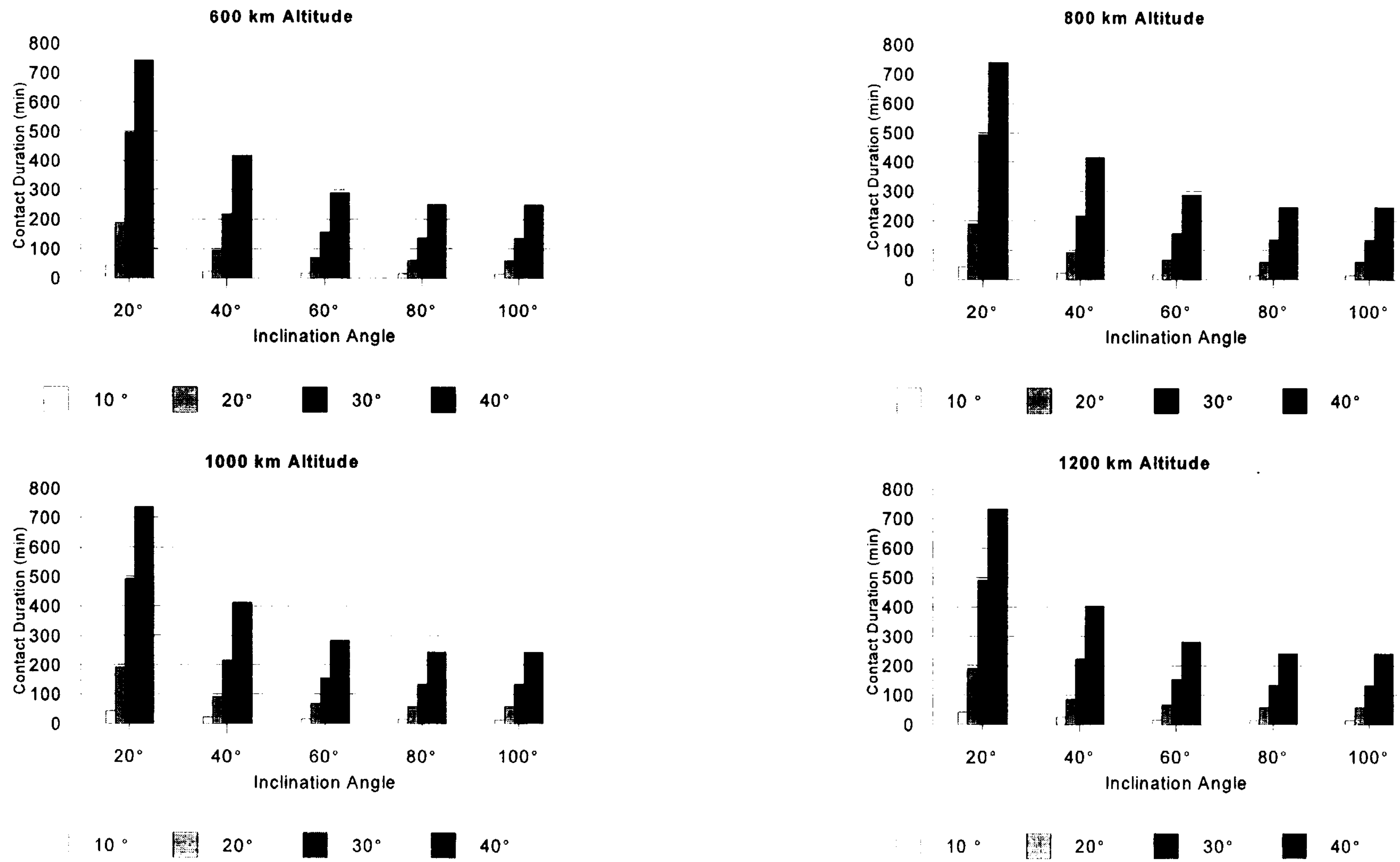


Figure 6. Total Constellation Average Contact Time as a Function of Orbital Altitude, Orbital Inclination Angle, and Antenna Cone Angle



SECTION 5 - CONCLUSIONS AND FURTHER WORK

Based on this improved study of the access times of a non-gimbaled antenna on a spinning satellite, we conclude that the basic technique previously described holds up when the simulation duration is extended to 30 days. In particular,

a. the improved simulation methodology with more accurate orbital element propagation techniques shows that the basic simulation methodology used in the original analysis was basically correct and the conclusions drawn from those initial studies were on the right track,

b. the non-gimbaled antenna pointing shows that at least 3 contacts per day are possible with existing technology and up to 15 contacts per day are possible with the correct choice of antenna and orbital inclination,

c. the antenna needed for the higher numbers of contacts per day is possible with current technology; for example, S-Band microstrip antennas with HPBW of 80° (40° cone angle) and gains of 5 dB, or microstrip arrays with HPBW of 40° (20° cone angle) and gains of 8 dB are available at NMSU and would be applicable to this mode of communication,

d. the non-gimbaled antenna pointing gives sufficient contact time through the entire Space Network constellation to make this communication mode reasonable to investigate for actual usage since the technique provides approximately 15 minutes per day at the low end up through several hundred minutes at the high end with the duration being a function of the orbital inclination and antenna HPBW,

e. the third TDRS covering the ZOE enhances the contact availability and total time per day for contacts.

Naturally, the exact amount of time available to a user will also be a function of the current network loading and mission operations needs.

The next step in this study is to apply these results to the improved TDRS link margins to compute the expected data throughput for the system. Since the improved TDRS link margins allow for lower signal levels, it is expected that these results will better show that this potential access method is viable for small satellites. This work will be presented in a subsequent technical report in this series.

SECTION 6 - REFERENCES

[1] S. Horan, W. P. Osborne, and T. Minnix, "Improved Small Satellite Access of the Space Network," NMSU-ECE-94-014, December 14, 1994.

[2] S. Horan, "Small Satellite Access of the Space Network", 9th AIAA/USU Conference on Small Satellites, Logan, UT, September, 1995.

[3] S. Horan, "Small Satellite Access of the Space Network," *Proc. Space Technology and Applications International Forum*, Albuquerque, NM, January 1996, p. 501-506.

[4] Analytical Graphics, "Satellite Tool Kit", King of Prussia, PA, 1996.

[5] Two line element file from the ftp site archive.afit.af.mil

Appendix - Acronym List

HPBW	Half Power Beam Width
LEO	Low Earth Orbit
MA	Mean Anomaly
MM	Mean Motion
NASA	National Aeronautics and Space Administration
RAAN	Right Ascension of the Ascending Node
SN	Space Network
STK	Satellite Tool Kit
TDRS	Tracking and Data Relay Satellite
TDRS-E	TDRS - East
TDRS-W	TDRS - West
TDRS-ZOE	TDRS - Zone of Exclusion
ZOE	Zone of Exclusion
ω_p	argument of perigee